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A New Machine for Producing Chunkwood

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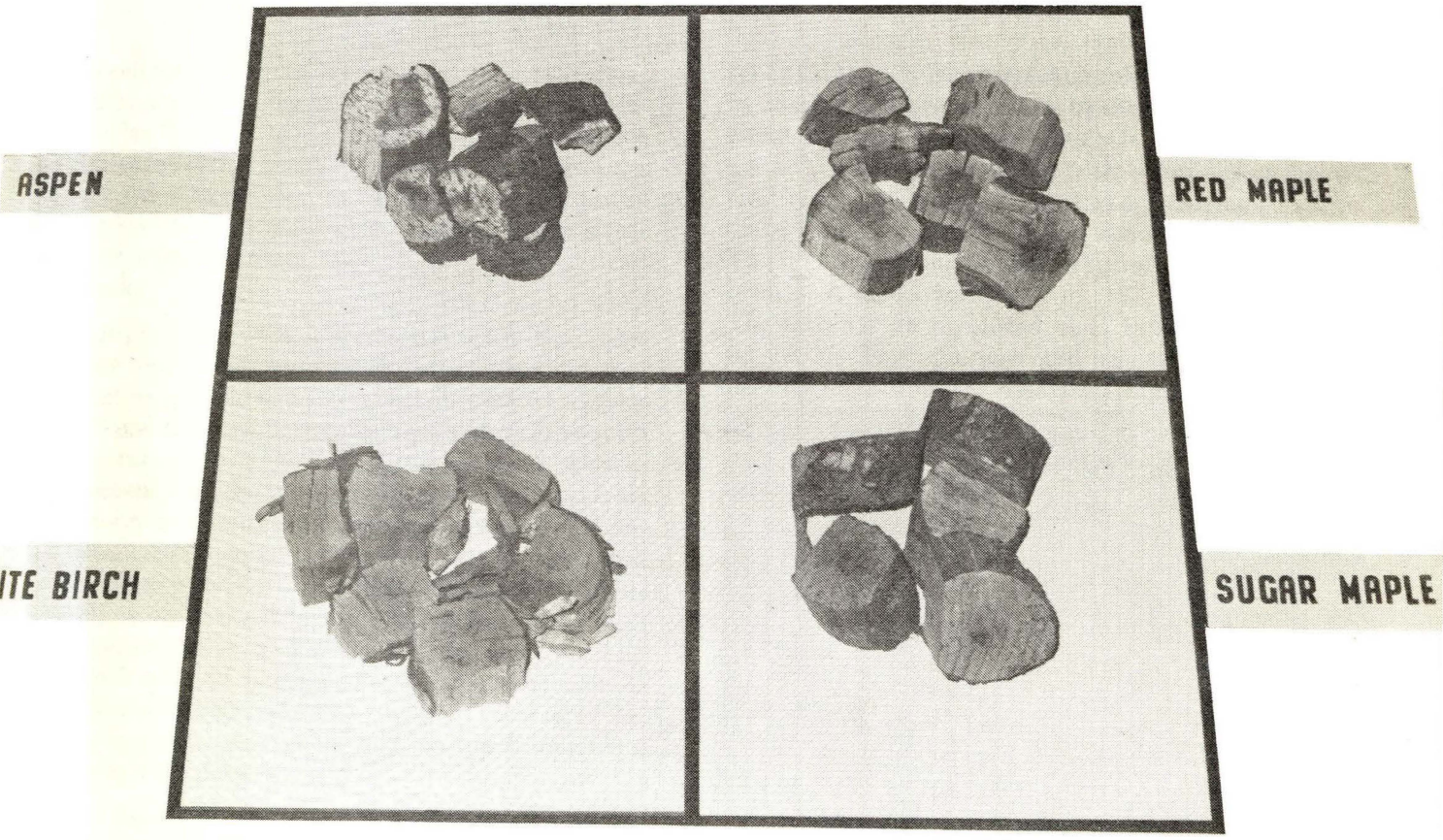

North Central Forest Experiment Station
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A NEW MACHINE FOR PRODUCING CHUNKWOOD

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As fossil fuel resources are depleted and prices escalate, there are increasing pressures for alternate industrial fuels. Wood is one alternative, particularly for industries located in heavily forested areas. However, a way is needed to reduce small trees and forest residue into a convenient form for direct combustion as a primary or supplementary fuel or as a wood gasifier feedstock.

Chips produced with conventional whole-tree chippers are small and not ideally suited for solid fuel combustors even though such chips are currently being used. Wood and coal, both solid fuels, generally require large combustion chambers. When wood is used to supplement coal, the typical pulp-size chips burn faster than stoker-sized coal, so the wood is burned off first. To obtain nearly equal combustion time for wood and coal, a larger wood particle is needed. Also, when pulp-size chips are burned in large industrial units, high stack gas velocities carry small particles and fly ash up the stack as solid particulates. Larger wood chunks would eliminate this problem — chunks ranging in size from a cigarette package up to 2- to 4-inch long discs from small diameter wood.

Also, the flakeboard industry would benefit from the longer fibers that the larger particles would yield. The Forest Products Laboratory in Madison, Wisconsin (Erickson 1976), recommended the development of a "fingerling" particle 2-1/2 to 3 inches long with a preferred cross sectional area of less than 1 square inch that could be ring flaked to yield the length properties desired for manufacturing exterior grade structural flakeboard. The chunks derived from this device can easily be further reduced in size to permit ring flaking.

Responding to this need we have developed two prototype devices to produce chunky wood particles to specified length. The largest chunks or discs produced by these machines are equal to the bolt diameter and about 2 inches long, with much fracturing along the grain. The chunks produced with either device can be readily used as energy wood or as a preferred intermediate form for manufacturing structural flakeboard. The first invention, a helical or spiral head chipper, has been described (Barwise *et al.* 1977, Erickson 1976). The latter is an involuted disc chunker (Barwise *et al.* 1982). This chunker and the results of initial prototype testing are described here (fig. 1).

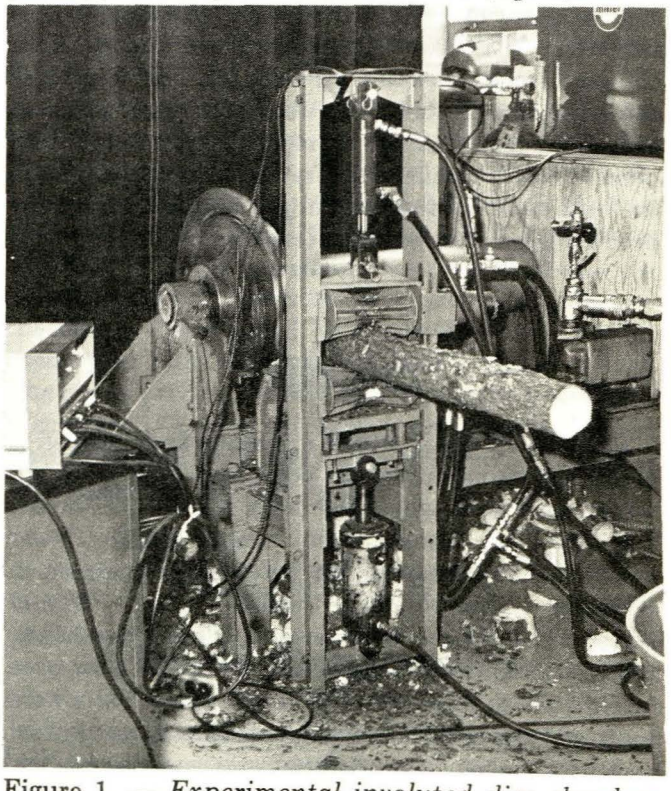

Figure 1. — *Experimental involuted disc chunker.*

THE STUDY

Machine Description

The experimental involuted disc chunker consists of a 24-inch-diameter disc mounted on a horizontal shaft supported by a pair of bearings secured to a rigid frame (fig. 2). A pair of blades 18 inches long, bent to a 12-inch radius, was mounted 180° apart at right angles to one face of the disc. The blades were mounted on the disc with the trailing end spiraling inward, i.e., involuted. The blades were tapered so that the leading cutting edge would project out 1/2-inch from the disc face and the trailing edge 5 inches, which is equivalent to maximum depth of the cut. The blades were sharpened to a 30-degree double bevel and were 1/4-inch thick.

An "anvil" was fabricated from a short piece of 6-inch diameter pipe and secured horizontally to the infeed frame so that the center of this pipe was 2 inches below the center of the disc. The inner end of the anvil was contoured to provide clearance for the rotating blade assembly.

The disc is driven by a hydraulic motor through a roller chain drive. The hydraulic motor, in turn, is operated by a hydraulic pump unit run by a 25 hp electric motor. Disc speeds were varied from 50 to 504 rpm by using different size sprockets.

A pair of hydraulically operated and spring-loaded feed rolls was mounted just ahead of the anvil to provide a firm yet flexible feed control over the log being chunked. These rolls were powered and positioned by a second hydraulic unit. The feed rolls were adjusted during the tests so that the workpiece was fed 15 to 20 percent faster than the theoretical feed rate to insure the bolt end met the feed stop for each cut, thereby producing uniform segment lengths.

Procedure

Because the experimental machine was developed to chunk only small diameter bolts, test bolts were obtained from trees with a diameter of 1.5 to 4.5 inches. The species tested were sugar maple *(Acer saccharum)*, red maple *(Acer rubrum)*, quaking aspen *(Populus tremuloides)*, white birch *(Betula papyrifera)*, American basswood *(Tilia americana)*, and jack pine *(Pinus banksiana)*. Selected trees were cut into two to three 8-foot bolts and coded. Discs were removed from the ends of each bolt of freshly cut wood to determine moisture content and specific gravity. Moisture content was determined on a green-weight

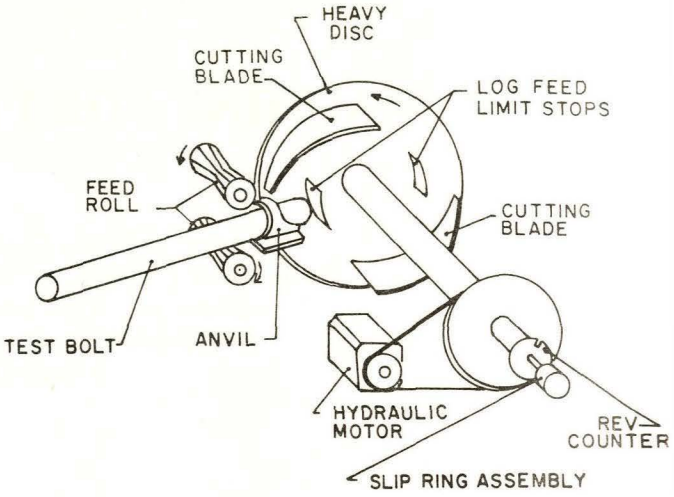

Figure 2. — *Simplified illustration of experimental involuted disc chunker.*

basis, specific gravity and density by dry weight-green volume as specified by TAPPI Standard T 18 m-53 (TAPPI 1967). Chipping tests were conducted on both frozen and as-cut/unfrozen wood. Bolts chipped frozen were stored in a freezer for about 2 months below 0°C.

To eliminate possible effects of end drying between time of cut and test, a 1-foot piece was cut from each end of the bolt immediately before chunking, leaving a 6-foot long test bolt.

The length, weight, species, and both end diameters of the test bolts were recorded. The large end of the test bolt was placed into the tubular anvil and the feed rollers positioned. With the cutting disc rotating at the desired test speed, the feed rolls and the recording instrumentation were activated simultaneously. Thus torque, torque integrated over time, and rpm were recorded on an oscillograph.

After completing the tests for a given species, the resulting chunks were put into a calibrated container to determine bulk density of the particles.

A sample of the chunkwood produced from each specie was later fed through a hammermill with the bar grate removed, to break the disc-sized chunks into smaller pieces similar to the "fingerling" particles described earlier. The resulting particles were classified by size.

Some of the larger test samples would not chunk because of insufficient power. To increase the power, the hydraulic power package was modified to increase the flow of oil to the hydraulic motor driving the cutting disc. This increased the disc rpm and available torque for a given sprocket size.

This modification worked as shown by the tests on sugar maple at 92 vs 105 rpm. At 92 rpm, only 47 percent of the bolts could be chunked with an average diameter of 2.3 inches. After the flow modification (105 rpm), 86 percent of the bolts were chunked, with an average diameter of 3.1 inches. Torque, horsepower, and energy used were recorded for all test bolts that were chunked.

Instrumentation

Four 350 ohm strain gages were arranged on the chipper shaft in a Wheatstone Bridge configuration and amplified so that a torque signal of appropriate amplitude was produced (fig. 3). This torque signal was simultaneously integrated and amplified within the system and recorded along with instantaneous torque and rpm on a recording oscillograph. To measure rpm, a photosensitive device was attached to the disc shaft, which produced a pulse with each revolution.

To initially calibrate the strain-gaged shaft and recording instruments, a known physical load was applied to the disc shaft while in a locked condition. No-load disc speed was determined by using a tachometer.

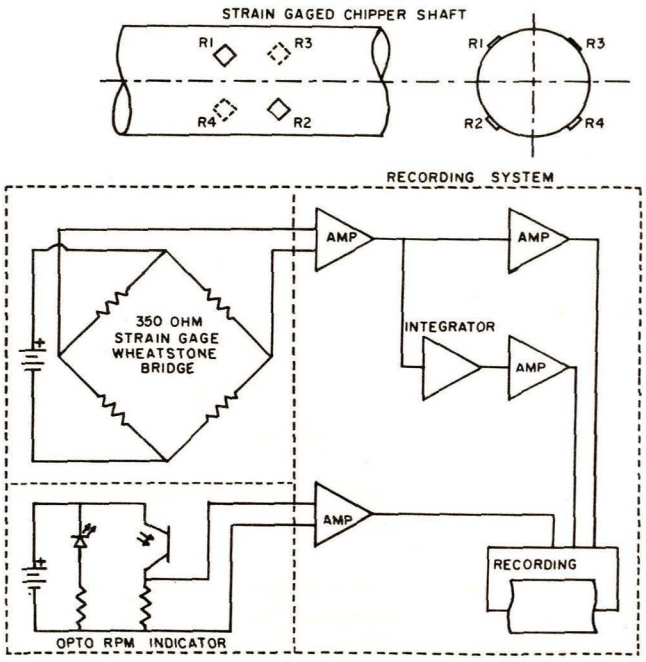

Figure 3. — *Schematic of instrumentation system.*

Data Analysis

Chunking production rate, average torque, average horsepower, and energy consumption were calculated from the descriptive data and the integrated torque curve by the following equations:

$$\text{Production rate } (ft^3/min) = \frac{\text{Volume chipped}}{\text{Time}}$$

$$\text{Average torque (ft-lb)} = \frac{\text{Calibration constant x integrated torque deflection}}{\text{Time}}$$

$$\text{Average horsepower (hp)} = \frac{\text{Average torque x rpm}^1}{5252}$$

$$\text{Energy}\left(\frac{\text{hp-min}}{ft^3}\right) = \frac{\text{Average hp}}{\text{Production rate}}$$

$$\text{Energy}\left(\frac{\text{hp-hr}}{\text{O.D. Ton}}\right) = \frac{33.33}{\text{Dry density}} \text{ x Energy}\left(\frac{\text{hp-min}}{ft^3}\right)$$

[1]*No load rpm.*

Scatter plots and analysis of the data were made to identify significant relationships. Originally, only four disc speeds ranging from 50 to 225 rpm were scheduled to be tested. When it was later determined that the machine could be modified to run at speeds up to 500 rpm, two additional series of tests were scheduled for birch and red maple.

A theoretical production rate was determined from the volume removed per cut, the number of cuts per revolution, and the rpm. Assuming a 2-1/2 inch nominal segment length removed per cut, the theoretical production rate in cubic feet per minute = 0.0023 rpm x $(DIA)^2$. A linear regression was used to obtain the actual production rate from timing data for all species combined. This yielded an r^2 value of 0.97. Actual production rate (cu ft/min) = 0.0018 rpm x $(DIA)^2$ The actual production rate was 20 percent lower than theoretical (fig. 4) primarily because of a decrease in disc rpm during chunking versus a theoretical calculation based on no-load rpm.

THE RESULTS

Power Requirements

The average torque was influenced by species, rpm, bolt diameter, and whether the wood was frozen or unfrozen (fig. 5). Limited data for red maple and

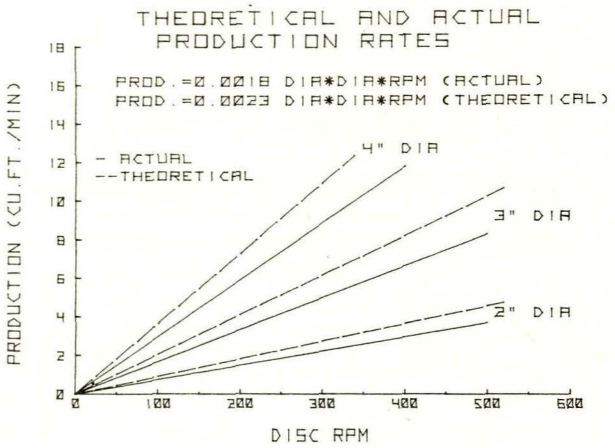

Figure 4. — *Comparison of chipping rates with 2- to 4-inch-diameter logs.*

white birch suggest that a large decrease in the average torque occurred between 225 and 336 rpm. Benefits derived from the higher rpm and flywheel energy should be investigated further, because low torque values result in lower horsepower and energy requirements.

Within the rpm range tested, twice as much energy was required to chunk sugar maple as the less dense aspen and basswood. For a given species, a major factor affecting energy requirements is rpm. For example, the average energy required to chunk red maple was 4.8 (hp-min/cu ft) in the range of 92 to 152 rpm but dropped to 1.5 (hp-min/cu ft) at 339 rpm.

The large diameter bolts required greater torque and energy to cut. However, because the production rate also increases with increasing bolt diameter, the incremental change in energy was proportionately less than the increase in torque. To illustrate, for sugar maple at 105 rpm, torque rose from 525 ft-lb for bolts 2.5 to 3.5 inches diameter to 943 ft-lb for those more than 3.5 inches — an increase of 80 percent. However, because there was a corresponding increase of 70 percent in the chunking production rate, the increase in required energy was only 10 percent — from 6.1 to

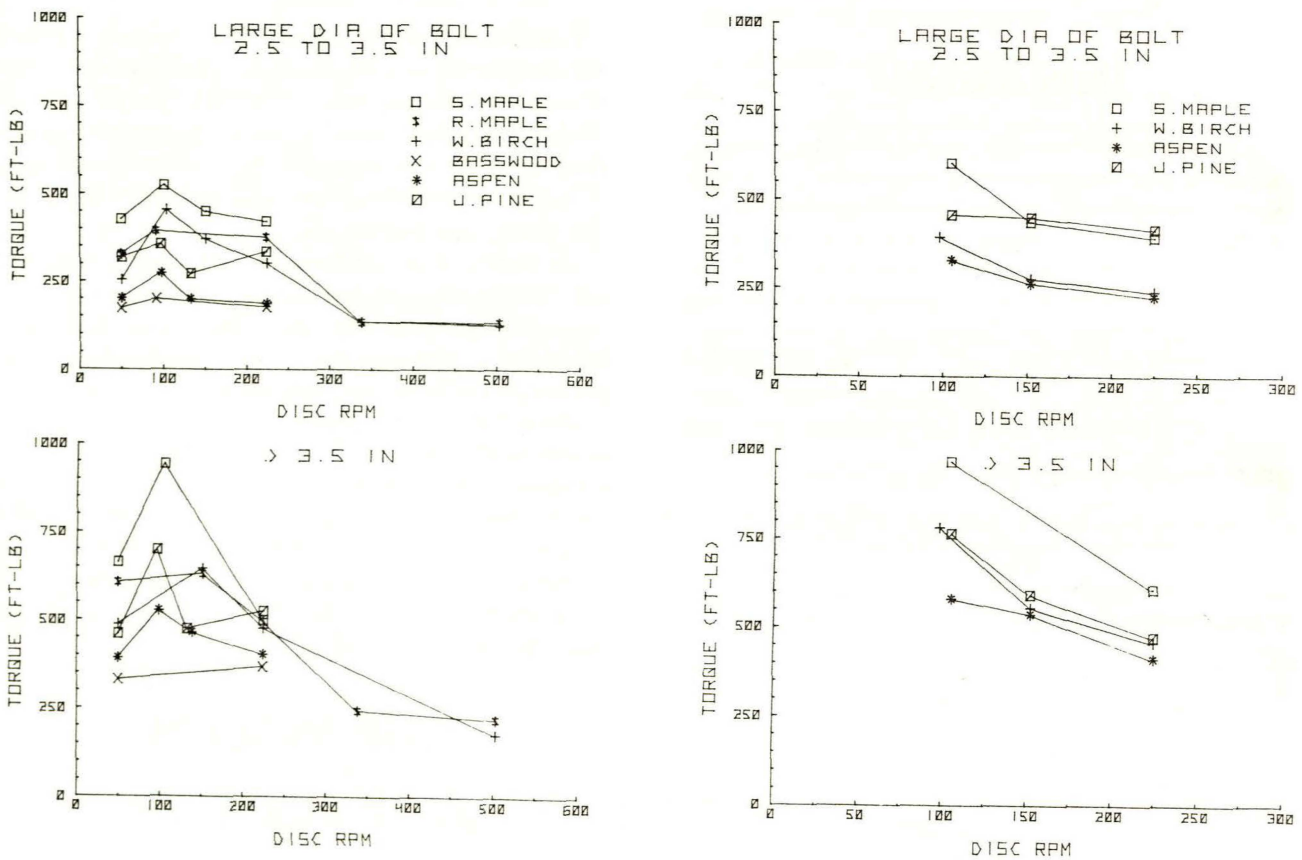

Figure 5. — *Torque for large and small diameter logs (left, unfrozen; right, frozen).*

6.8 hp-min/cu ft as the bolt size increased over the range indicated.

Horsepower is a product of rpm and torque; hence, factors affecting torque also affect horsepower (fig. 6).

The limited power of the prototype machines restricted bolt diameter that could be processed. Bolts larger than 3.5 inches in diameter required twice as much horsepower as those from 2.5 to 3.5 inches. In some cases, the horsepower used was greater than the theoretical 25 hp supplied, with additional power coming from the flywheel effect of the disc. However, 88 of the 700 test bolts could not be chipped because of insufficient power.

For user convenience, two sets of graphs showing the energy required to produce the wood chunks are included. One set presents energy required in terms of cubic feet of wood (fig. 7) while the second set shows the energy required to produce oven-dry tons (fig. 8). The apparent difference in energy levels for each species is due to the various wood density and moisture contents. The graphs show the strong effect of disc rpm as well as the influence of diameter and frozen versus unfrozen condition.

Chunk Output

The experimental involuted disc machine produces large wood chunks that may be of preferred size for certain types of solid fuel, large scale industrial combustors, and perhaps certain gasifiers.

Because of its effect on storage, handling, and heating value, the bulk density of these large chunks is of interest. To determine the bulk density of these chunks, a 36 cu ft box was pre-calibrated to read cubic foot volume when the chunks were leveled in the box. The entire box with chunks was weighed and the box's weight deducted to give the green weight of chunks. The bulk density was obtained by dividing the recorded green weight of chunks in the box by the cubic-foot volume:

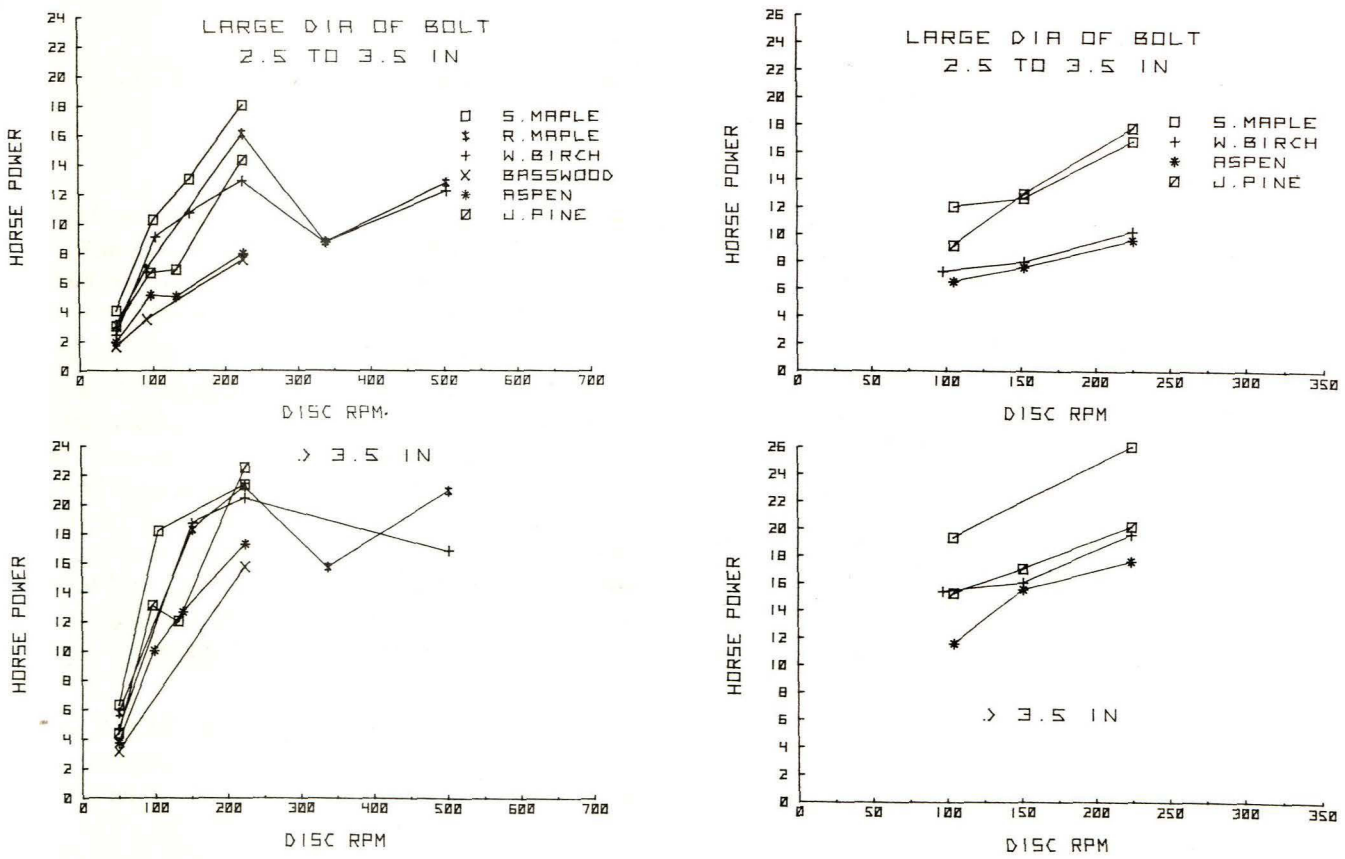

Figure 6. — *Horsepower to chunk large and small diameter logs (left, unfrozen; right frozen).*

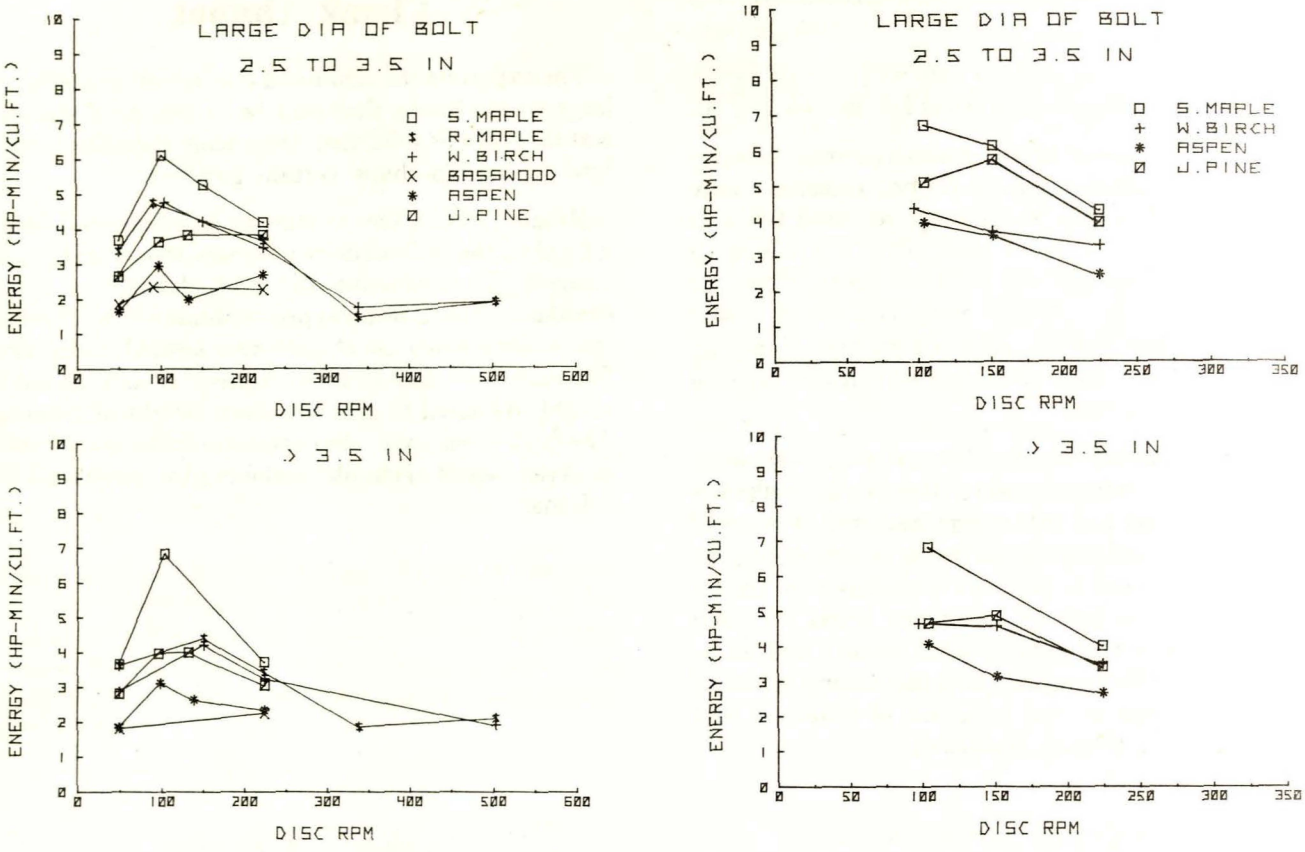

Figure 7. — *Energy for involuted disc chunker - large and small diameter logs (left, unfrozen; right, frozen).*

Species	Average bulk density	Solid volume[2]
	(lb/ft³)	*(Percent)*
Basswood	16.1	38
Aspen	23.4	48
Jack pine	21.2	42
White birch	24.0	42
Red maple	22.1	44
Sugar maple	25.4	44

Conventional green whole-tree chips have a bulk density of 15 to 18 pounds per cubic foot (University of Washington n.d.).

The chunks differed somewhat in size depending on species and on whether the material was unfrozen or frozen at time of chunking — many of the pieces were entire discs, like oversize hockey pucks. These chunks had some internal fracturing along the grain which facilitates subsequent reduction in size or drying of the blocks. Processing of frozen wood, although requiring up to 30 percent more energy, produced particles with much greater internal fracturing.

Though not completely uniform, the chunks or discs from the experimental machine are about 2 inches long, with a maximum cross-section equal to the diameter of the bolt. For certain types of combustors, these discs may still be too large. They are definitely too large to be ring flaked as furnish for flakeboard. To further reduce them in size, they were passed through a modified hammermill, and screened on a round-hole Williams Classifier (table 1). The moisture content of the resulting "fingerling"particles was also determined.

Most wood segments were cut from the test bolts to the specified fiber length. The subsequent hammermilling does not affect the length of particles — only their cross-sectional size (fig. 9). The hammermilled output is still suitable for fuel. Of key importance, quality ring flakes for making structural grade flakeboard can be produced from the particles elongated in the grain direction. As can be seen from

[2]*Percent solid volume = green weight/cu ft of chunks divided by green weight/cu ft solid wood.*

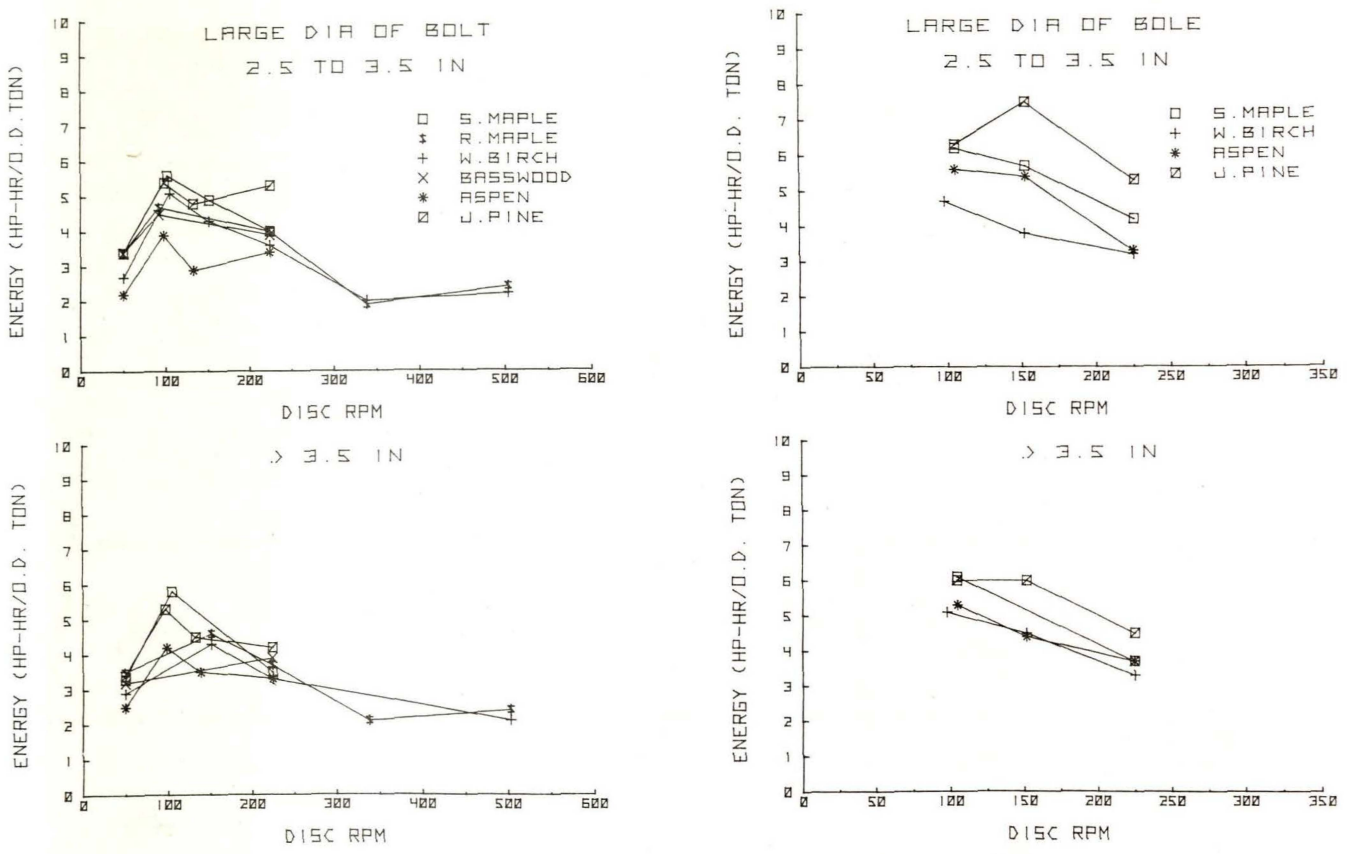

Figure 8. — *Chunker energy in terms of oven-dry tons (left, unfrozen; right, frozen).*

the screen analysis (table 1), most of the particles (85 to 95 percent depending on species) were retained on the 5/8-inch or larger screen. The particles still remained about 2-1/2 inches long for the 3/8-inch and larger screen fractions (fingerlings). It is these elongated particles from which quality ring flakes can be made.

Table 1. — *Screening analysis and moisture content of hammermilled output*

	Hammermilling and screening breakdown (inches)						Moisture content
	+1-1/8	5/8	3/8	3/16	Fines	Total	
	Percent of input						Percent
Basswood	82	12	3	2	1	100	53
Aspen	70	18	6	4	2	100	51
Jack pine	60	25	8	5	2	100	51
White birch	74	19	4	2	1	100	43
Red maple	75	20	3	1	1	100	39
Sugar maple	81	13	3	2	1	100	37

CONCLUSION

Preliminary tests of this experimental disc chunker demonstrated the technical feasibility of producing chunkwood from small diameter wood.

This preliminary research was considered successful enough to warrant the design of a second prototype. Changes include a more adequate power source, which was the limiting factor in this investigation, and the ability to handle logs of larger diameter. Testing of the second prototype will be reported in the future.

LITERATURE CITED

Barwise, Robert D., Rodger A. Arola, and Edsel D. Matson. 1982. Involuted disc slicer. Patent application filed February 26, 1982.

Barwise, Robert D., Rodger A. Arola, and John R. Erickson. 1977. Helical head comminuting shear. U.S. Patent 4,053,004. October 11.

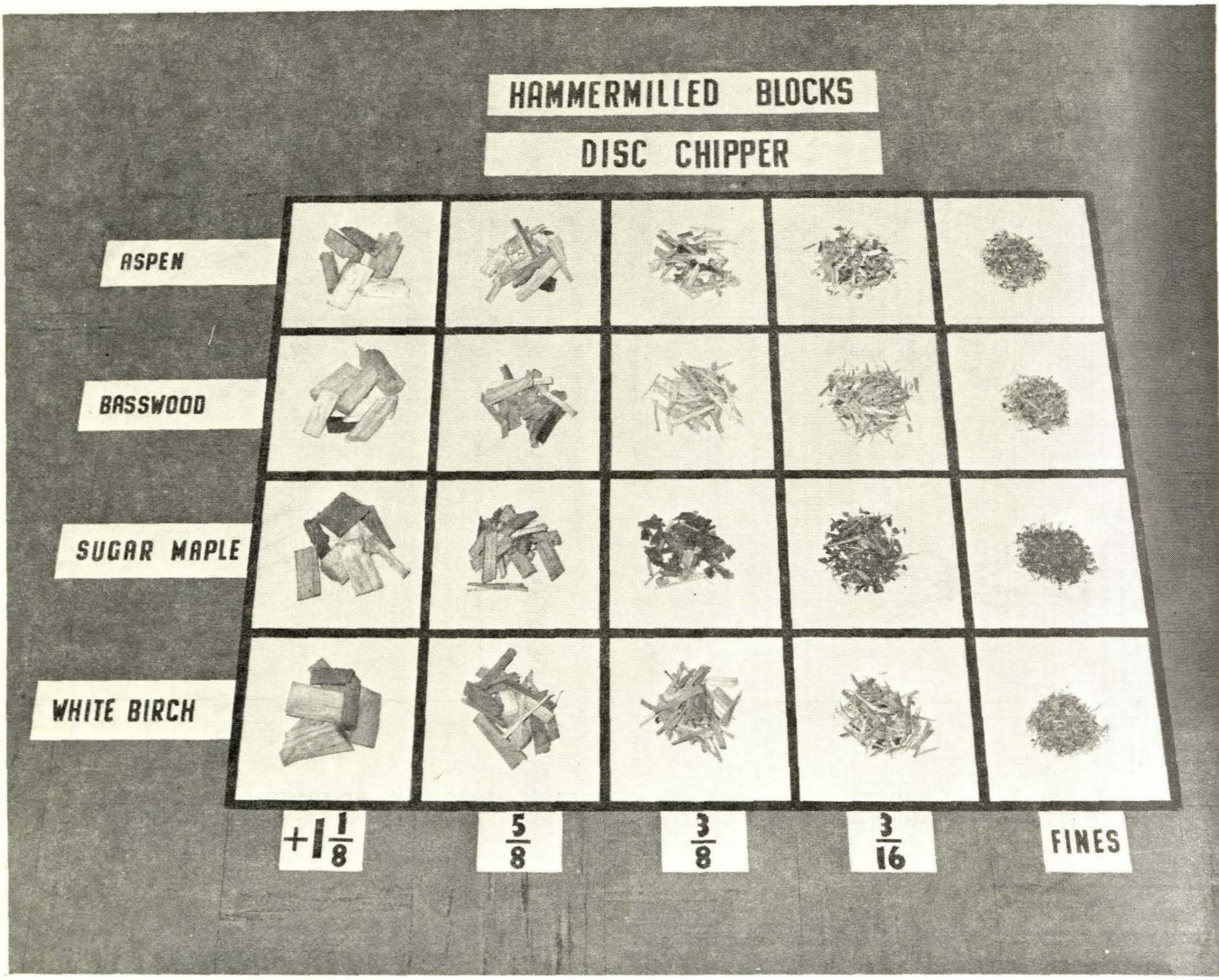

Figure 9. — *Sample particles after hammermilling of chunks.*

Erickson, John R. 1976. Exploratory trials with a spiral-head chipper to make hardwood "fingerling" chips for ring flakers. Forest Products Journal 26(6):50-53.

Technical Association of the Pulp and Paper Industry. 1967. TAPPI Standard T 18m-53. Specific gravity (density) and moisture content of pulpwood. 4 p.

University of Washington. [n.d.]. Conversion factors for Pacific Northwest forest products. Institute of Forest Products, College of Forest Resources, University of Washington, Seattle, Washington.

Arola, Rodger A., Robert C. Radcliffe, Sharon A. Winsauer, and Edsel D. Matson.

1982. A new machine for producing chunkwood. U.S. Department of Agriculture Forest Service, Research Paper NC-211, 8 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Describes and presents the results of performance testing for an experimental machine that produces chunky wood particles. These wood chunks can be used by the flakeboard industry or as energy wood.

KEY WORDS: Energy wood, flakeboard industry, wood comminution, wood conversion, chipping.

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